PC Based Infrared Scene Generation Development

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The U.S. Air Force Electronic Warfare Evaluation Simulator (AFEWES) is a government-owned, contractor-operated electronic warfare test facility located at Air Force Plant 4, in Fort Worth, Texas. The AFEWES is a Test and Evaluation (T&E) resource of the Air Force Flight Test Center (AFFTC), 412 Electronic Warfare Group (EWG), Edwards Air Force Base, California. AFEWES' mission is to perform effectiveness testing of Department of Defense (DoD) and allied electronic countermeasure techniques to enhance aircraft and aircrew survivability in combat. This paper describes the multi-service and contractor team that successfully defined, designed, developed, tested and implemented state of the art infrared PC based scene generator to be used by DoD. The paper also highlights: Team requirements and low cost solution, Leveraging government owned assets and developing partnerships across DoD.

I. Introduction

This paper describes how a high risk Small Business Innovative Research (SBIR) effort paid off for DoD and DoD contractors for generating complex infrared (IR) scenes using commercial-off-the-shelf technology. In 2002, an AFEWES' SBIR proposal to develop a PC-based, dynamic, real-time IR scene generator to drive a 512X512-pixel array was approved and funded by the AFFTC SBIR office. The Phase I competitive effort was to develop a PC-based, cost effective, highly capable Infrared Scene Generator (IRSG) to simulate real-time, high-fidelity target/countermeasure scenes. The requirement was for a dynamic scene generator that could react to simulated IR threat hardware, system under test (SUT), and scenario changes to produce a scene based on the unfolding engagement scenario. There were two promising Phase I SBIR developments. The most promising Phase I SBIR led to a Phase II award.[3]

II. Background

In order to accomplish the AFEWES T&E mission, we develop and operate very high-fidelity radio frequency (RF) and IR threat simulators to evaluate the effectiveness of DoD and allied EW systems in a controlled, ground-based environment. The key features of AFEWES testing include actual frequencies or wavelengths, in real-time, with dynamic engagement scenarios.

In 2002 the AFEWES Infrared Counter Measures (IRCM) test facility was capable of simulating a complete IRCM test environment. This includes IR missiles in flight, aircraft in flight, and various IRCM; including flares and Directed Energy (DE) countermeasure such as lamp-based or laser jamming systems. The simulation of IR missiles in flight uses hardware mounted in a nine axis flight motion table. The simulated missiles operate using a six degree-of-freedom Fly Out Model (FOM). Aircraft signatures and IR countermeasures are simulated with xenon arc-lamp, or blackbody, or laser sources. Real-time computers control the source position and output, thereby creating the proper spatial and radiometric characteristics of a target during missile closure. IR missiles come in various forms, but the most commonly known are the shoulder launched missile that terrorists have used to target military and civilian aircraft. Historically AFEWES used the IR sources to simulate the targets (US aircraft) that these seekers would try to shoot down. These "point source" target presentations have an accurate IR signature of the heat from hot spots such as the engines, but did little to project a complete IR image of the entire aircraft for imaging infrared seekers. This additional IR energy and other extended IR sources would require AFEWES to use a resistive array

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3 Air Force FY 03.1 SBIR Solicitation, AF03-264 PC Based Dynamic Real-Time Infrared Image Generation Capability http://www.acq.osd.mil/osbp/sbir/solicitations/sbir031/af031.htm

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projection system. Our goal was to develop a cost effective and supportable IR scene generator using state-of-the-art personal computer (PC) technology.[4]

III. Technology Shortfall

The selected solution for the simulation shortfall was to use mature Resistive Array (RA) technology driven by a high-speed PC. A RA is a small grid of micro-resistors, physically the size of a postage stamp, that has over 250,000 individual resistors, all controlled by a computer. Putting small electric currents across these micro-resistors causes a thermal pattern that looks like the IR image of an aircraft. However, the electrical current amplitude and duration has to be controlled across all quarter million resistors to make the IR scene look correct or like the “real world” to a missile seeker. In addition, the IR scene changes as the missile approaches the aircraft. Currently, expensive and complex dedicated scene generation computers and specialized hardware are needed to drive the resistive array to present a dynamic image necessary for accurate testing. The SBIR challenge, how to create a RA scene that is both accurate and affordable? Since this problem of developing an affordable scene generation capability was pushing the PC technology envelope, AFEWES successfully competed for SBIR funding.

IV. Team Building and Requirements

AFEWES in the past involved subject matter experts (SME) from across DoD to solve complex problems such as those posed by the simulation requirements.[5] The SBIR Phase I team was limited to the developer of the resistive array, IR threat experts, and some users of the current specialized IR scene generation technology. After the SBIR Phase II award, the team membership expanded to include all DoD users of scene generation technologies. With the understanding gained from the SMEs in the first team building exercise, AFEWES was able to develop the requirements to issue the SBIR solicitation titled Infrared Scene Generation (IRSG).

A. SBIR Phase I Solicitation, Proposal, and Concept

The IRSG FY03.1 SBIR solicitation produced several Phase I Proposals. The DoD team evaluated the proposals and recommended two Phase I contractors with proposals that presented possible solutions be funded to produce Phase I concepts.[6] At the end of the FY03.1 SBIR Phase I performance period, the team evaluated the contractors concepts and recommended funding for Kinetics Inc., a small company located in Stevenson, Washington, to go forward into the Phase II effort to develop a prototype. The Phase I Final Report documented how a scene generation capability was attainable with the current generation of PC hardware while using open-source and government-owned scene generation software.[7]

The principle areas researched were techniques to generate infrared imagery with 16-bits of dynamic range while running a representative surface-to-air engagement scenario at frame rates of over 200 frames per second. Techniques to solve the limitation in the pixel dynamic range, antialiasing, and synchronization were addressed.[7]

B. IRSG Build #1

The IRSG consists of scene generation software necessary to compute radiometrically correct scenes in real-time. The Real-Time (RT) version of the government-owned scene generation Composite Hardbody and Missile Plume (CHAMP) software, RT-CHAMP, was selected to support this effort since it has been demonstrated to support Hardware in the Loop (HITL) testing, is actively supported by the Munitions Directorate of the Air Force Research Laboratory (AFRL), and is currently used in other HITL facilities such as the Guided Weapons Evaluation Facility (GWEF) and the Missile and Space Intelligence Center (MSIC). RT-CHAMP is government owned software that will enable the IRSG to be cost-effectively upgraded over time to adapt to changing mission requirements and host hardware architectures. No other real-time scene generation software is known to provide radiometrically correct hardbody and plume signatures while using non-proprietary, government-owned software approaches that can be thoroughly examined by the customer and peers to verify and scrutinize the modeling approach.[7]

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4 AFEWES Executive Overview Presentation

5 Lessons Learned for Streamlined Operations, Increasing Capability, and Effectiveness Through Partnerships

6 DoD SBIR FY03.1 – Solicitation Selections w/ abstracts, http://www.dodsbir.net/selections/abs031/dodabs031.htm#af

7 SBIR Phase I Final Report, 22 March 2004, Titled: PC-Based Dynamic Real-Time Infrared Image Generation Capability, Delivered on Contract FA9300-04-0027 01 JUNE 2004, CDRL B003

RT-CHAMP can compute the signature of various scene objects that include airborne targets, exhaust plumes, countermeasures, and environmental backgrounds. RT-CHAMP allows the state parameters for scene objects, environment, and seeker to be updated over the duration of the HITL test. The primary scene object state parameters are the object's kinematics that allows position and orientation changes to occur over time. Additional scene object state parameters needed during the simulation include the 1) thermodynamic state due to aero-thermal and environmental heating and 2) propulsive state due to engine operational changes. Typically, for HITL applications, the states of the various scene objects follow a script where the time dependent kinematics, thermodynamic, and propulsive attributes are computed prior to the HITL test.[8]

The environment state affects the scene object lighting (sunshine, skyshine, and earthshine) and radiation propagation through the atmosphere to the seeker. The environment state changes as a function of time-of-day and time-of-year as the solar position changes over time. For surface-to-air HITL applications where the simulation lasts less than one minute, the environmental state can be assumed to be constant. Thus, the environment state can be pre-computed during an initiation step to the HITL test for the nominal time and date of the simulation.

Thermal and propulsion state calculations are computationally intensive and usually cannot be performed in real-time. To maintain real-time performance for these physical states, RT-CHAMP performs interpolation operations on precomputed databases allowing continuous variations of the state to change over time. To maintain traceability to accepted practices, RT-CHAMP utilizes well-defined state database formats allowing the database to be populated by external, higher fidelity computer programs. This database approach also allows state data derived from advanced specialized codes or measured data to be utilized by RT-CHAMP. This approach does not marry RT-CHAMP to a particular data source, but allows RT-CHAMP to utilize the most appropriate input data for a particular HITL application.[8]

C. IRSG Builds #2, #3, and #4

The design approach for this development was to take advantage of new and emerging technologies and leverage existing tools and test capabilities. This development continues to monitor the advancements in technology as provided in the contract. This development performs benchmarking as well as regression testing to determine when a new technology insertion is warranted. Since the start, the system has migrated through three microprocessor/system boards, three graphic boards and three versions of the Linux operating system. The network communication card is part of the AFEWES communication and has not changed. Thus the IRSG is delivered in four Builds. IRSG Build #1 delivered the initial IRSG capability discussed above. IRSG Builds #2, #3, and #4 focuses on emerging technologies, integrating countermeasures, developing CHAMP/RT-CHAMP signatures, and validation. [9]

This SBIR developed a PC-based real-time IR scene generation system capable of driving a 16-bit projection system with image sizes up to 2048 x 1536 at frame rates exceeding 200 frames per second to support closed loop testing of guided-weapon seeker systems.[8]

Currently the IRSG is running RT-CHAMP version 2.1.7 (R287) and configuration is shown in Table 1.

Table 1 IRSG Components

Commercial-Off-The-Shelf Components	
CPU	64-bit AMD Processors
Graphics	NVIDIA (8800)
Network	SCRAMNET
Operating System	Linux (RedHat Enterprise 5)

1. The hardware utilized AMD 64-bit processors running the Linux operating system. The 64-bit hardware provided considerably better performance to support the floating-point intensive IR signature calculations as well as supporting applications with large memory requirements.[8]

2. The graphic hardware for this effort was manufactured by NVIDIA®. This graphics hardware provides support for internal 32-bit floating-point operations.[8]

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8 Summation Report, PC Based Dynamic Real-Time Infrared Image Generation Capability SBIR Topic Number AF03-264, http://www.sbirsttrmall.com/

[9] SBIR Overview Status presentation dated: 11 July 2007, delivered on contract: FA9300-04-0027

3. The network hardware consisted of SCRAMNet+ real-time PCI network cards, which provided very low (submicrosecond) communication latencies to support process synchronization.[8]

4. RT-CHAMP was measured at triangle processing rates up to 16,000,000 triangles per second.[8]

The IRSG team successfully completed training by the SBIR contractor on the development and use of target models and countermeasure (CM) signatures to include setup, operation, and maintenance of the IRSG to support T&E effectiveness assessments for various aircraft targets in a variety of atmospheric conditions. This training included flowfield effects on Special Material Decoys (SMDs) should they pass through the target's exhaust flowfield. The T&E and S&T (Science and Technology) IRSG team now have a common procedure for creating unique target models to support development activities. In addition the IRSG team received training on the enhanced background modeling tool that automates the capability to generate sky backgrounds as a function of geographic position, time-of-day, local weather conditions, and sensor bandpass via a graphical user interface supplied under the SBIR contract[9]

D. Aircraft Targets and Countermeasures

Along with the RT-CHAMP development the IRSG project developed RT-CHAMP IR target and countermeasure models. The IRSG team members acquired CHAMP target models, CHAMP countermeasure models, wireframe models, and documentation from several sources for conversion to RT-CHAMP to run on the IRSG. These models include wide body transport aircraft, fast moving airborne interceptors, and helicopters. RT-CHAMP models of current flare inventory as well as flares in development are modeled in RT-CHAMP. Additional models are competed and available. Others are in the development stage. All completed target and countermeasure models have been validated.

V. Conclusion

Normally SIBR projects have limited interest due to the narrow application area. Because of the remarkable success and broad application potential of this SIBR, the technical reviews drew large audiences and currently deliveries include 33 systems to 12 different facilities. One facility using the IRSG reports that switching to a COTS PC running Linux reduced maintenance costs, as well as expensive software licenses. They plan to build five simulator systems, for $15,000, saving almost $150,000. That represents a considerable cost savings to the user. Another user reports that yearly cost savings range from the lowest cost of approximately $3,000 per year to as high as $100,000 per year depending on which system capability is used for comparison. The bottom line; the 412th Electronic Warfare Group and a dozen test facilities across DoD are benefiting from a single SBIR development.

The SBIR IRSG development enhanced research laboratories and test environments. Now testers, like AFEWES, can assess the contribution of defensive tactics and techniques in a variety of combinations to disrupt, shape, and exploit the adversarial use of the infrared spectrum. This development demonstrated and delivered cost effective, commercial-off-the-shelf technology with open source Linux operating system, and government-owned software that can be utilized to support HITL and digital simulation facilities to research advanced War Fighter technologies. In addition, higher performance with increased fidelity has been measured. Now DoD testers can more thoroughly evaluate special material decoys, fixed wing and rotary aircraft, as well as assess the performance of IR sensors in high clutter backgrounds using portable, non-proprietary, demonstrated computational hardware which achieves a cost reduction of two orders of magnitude over traditional approaches. In addition, the delivered and demonstrated low-cost IRSG capability allows DoD researchers and designers to have ready access to signature tools developed with the cooperation and participation of subject matter experts during technical peer reviews and training by the IRSG team. In summary, the increase and fidelity of the SBIR developed PC-based real-time infrared scene generator enhancements allows many advanced applications to be researched including: [8]

- Multi-color Sensors
- Multi-platform Sensors
- Near Point-Source Anti-Aliasing
- Temporal and Spatial Blurring
- Source Shadowing
- Targeting and Discrimination Algorithm Research and Development
- Distributed Scene Generation

The scene generation simulation software applied to this effort extended the Government-owned RT-CHAMP signature code developed by Kinetics, Inc. to produce physically correct radiance images of missiles, aircraft, helicopters, countermeasures, and backgrounds. Software testing was performed to verify the accuracy of the synthetic signatures by comparing against data (when available) and other published sources. [8]

AFEWES developed partnerships with other DoD facilities with a common desire to have cost-effective standardized tools and techniques for Scene Generation and Projection. Significant achievements are now being realized across DoD and industry because of the involvement of other interested subject matter experts across the nation.

Acronyms

AFEWES	U.S. Air Force Electronic Warfare Evaluation Simulator
AFFTC	Air Force Flight Test Center
AFRL	Air Force Research Laboratory
CHAMP	Composite Hardbody and Missile Plume
CM	countermeasure
DE	Directed Energy
DoD	Department of Defense
EWG	Electronic Warfare Group
GWEF	Guided Weapons Evaluation Facility
HITL	Hardware in the Loop
IR	Infrared
IRCM	Infrared Counter Measures
IRSG	Infrared Scene Generator
MSIC	Missile and Space Intelligence Center
PC	Personal Computer
RA	Resistive Array
RF	Radio Frequency
RT	Real-Time
RT-CHAMP	Real-Time Composite Hardbody and Missile Plume
S&T	Science and Technology
SBIR	Small Business Innovative Research
SMD	Special Material Decoys
SME	Subject Matter Expert
SUT	System Under Test
T&E	Test and Evaluation